Halliday ♦ Resnick ♦ Walker

FUNDAMENTALS OF PHYSICS
SIXTH EDITION

Selected Solutions

Chapter 18

18.13
18.27
18.35
18.55

13. Let L_1 be the distance from the closer speaker to the listener. The distance from the other speaker to the listener is $L_2 = \sqrt{L_1^2 + d^2}$, where d is the distance between the speakers. The phase difference at the listener is $\phi = 2\pi(L_2 - L_1)/\lambda$, where λ is the wavelength.

(a) For a minimum in intensity at the listener, $\phi = (2n+1)\pi$, where n is an integer. Thus $\lambda = 2(L_2 - L_1)/(2n+1)$. The frequency is

$$f = \frac{v}{\lambda} = \frac{(2n+1)v}{2\left(\sqrt{L_1^2 + d^2} - L_1\right)} = \frac{(2n+1)(343\,\mathrm{m/s})}{2\left(\sqrt{(3.75\,\mathrm{m})^2 + (2.00\,\mathrm{m})^2} - 3.75\,\mathrm{m}\right)} = (2n+1)(343\,\mathrm{Hz})\ .$$

Now $20,000/343 = 58.3$, so $2n+1$ must range from 0 to 57 for the frequency to be in the audible range. This means n ranges from 1 to 28 and $f = 1029$, 1715, ..., 19550 Hz.

(b) For a maximum in intensity at the listener, $\phi = 2n\pi$, where n is any positive integer. Thus $\lambda = (1/n)\left(\sqrt{L_1^2 + d^2} - L_1\right)$ and

$$f = \frac{v}{\lambda} = \frac{nv}{\sqrt{L_1^2 + d^2} - L_1} = \frac{n(343\,\mathrm{m/s})}{\sqrt{(3.75\,\mathrm{m})^2 + (2.00\,\mathrm{m})^2} - 3.75\,\mathrm{m}} = n(686\,\mathrm{Hz})\ .$$

Since $20,000/686 = 29.2$, n must be in the range from 1 to 29 for the frequency to be audible and $f = 686$, 1372, ..., 19890 Hz.

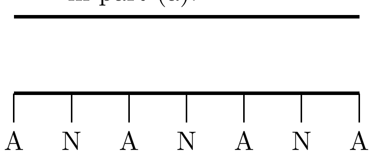
27. (a) Let P be the power output of the source. This is the rate at which energy crosses the surface of any sphere centered at the source and is therefore equal to the product of the intensity I at the sphere surface and the area of the sphere. For a sphere of radius r, $P = 4\pi r^2 I$ and $I = P/4\pi r^2$. The intensity is proportional to the square of the displacement amplitude s_m. If we write $I = Cs_m^2$, where C is a constant of proportionality, then $Cs_m^2 = P/4\pi r^2$. Thus $s_m = \sqrt{P/4\pi r^2 C} = \left(\sqrt{P/4\pi C}\right)(1/r)$. The displacement amplitude is proportional to the reciprocal of the distance from the source. We take the wave to be sinusoidal. It travels radially outward from the source, with points on a sphere of radius r in phase. If ω is the angular frequency and k is the angular wave number then the time dependence is $\sin(kr - \omega t)$. Letting $b = \sqrt{P/4\pi C}$, the displacement wave is then given by

$$s(r,t) = \sqrt{\frac{P}{4\pi C}}\,\frac{1}{r}\sin(kr - \omega t) = \frac{b}{r}\sin(kr - \omega t) \ .$$

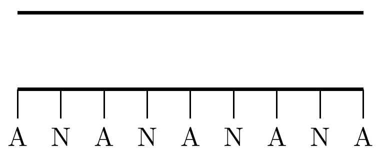
(b) Since s and r both have dimensions of length and the trigonometric function is dimensionless, the dimensions of b must be length squared.

35. (a) Since the pipe is open at both ends there are displacement antinodes at both ends and an integer number of half-wavelengths fit into the length of the pipe. If L is the pipe length and λ is the wavelength then $\lambda = 2L/n$, where n is an integer. If v is the speed of sound then the resonant frequencies are given by $f = v/\lambda = nv/2L$. Now $L = 0.457\,\mathrm{m}$, so $f = n(344\,\mathrm{m/s})/2(0.457\,\mathrm{m}) = 376.4n\,\mathrm{Hz}$. To find the resonant frequencies that lie between $1000\,\mathrm{Hz}$ and $2000\,\mathrm{Hz}$, first set $f = 1000\,\mathrm{Hz}$ and solve for n, then set $f = 2000\,\mathrm{Hz}$ and again solve for n. You should get 2.66 and 5.32. This means $n = 3$, 4, and 5 are the appropriate values of n. For $n = 3$, $f = 3(376.4\,\mathrm{Hz}) = 1129\,\mathrm{Hz}$; for $n = 4$, $f = 4(376.4\,\mathrm{Hz}) = 1526\,\mathrm{Hz}$; and for $n = 5$, $f = 5(376.4\,\mathrm{Hz}) = 1882\,\mathrm{Hz}$.

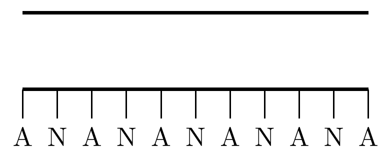
(b) For any integer value of n the displacement has n nodes and $n + 1$ antinodes, counting the ends. The nodes (N) and antinodes (A) are marked on the diagrams below for the three resonances found in part (a).



$n = 3$



$n = 4$



$n = 5$

55. (a) The expression for the Doppler shifted frequency is

$$f' = f\,\frac{v \pm v_D}{v \mp v_S}\,,$$

where f is the unshifted frequency, v is the speed of sound, v_D is the speed of the detector (the uncle), and v_S is the speed of the source (the locomotive). All speeds are relative to the air. The uncle is at rest with respect to the air, so $v_D = 0$. The speed of the source is $v_S = 10\,\mathrm{m/s}$. Since the locomotive is moving away from the uncle the frequency decreases and we use the plus sign in the denominator. Thus

$$f' = f\,\frac{v}{v + v_S} = (500.0\,\mathrm{Hz})\left(\frac{343\,\mathrm{m/s}}{343\,\mathrm{m/s} + 10.00\,\mathrm{m/s}}\right) = 485.8\ \mathrm{Hz}\ .$$

(b) The girl is now the detector. Relative to the air she is moving with speed $v_D = 10.00\,\mathrm{m/s}$ toward the source. This tends to increase the frequency and we use the plus sign in the numerator. The source is moving at $v_S = 10.00\,\mathrm{m/s}$ away from the girl. This tends to decrease the frequency and we use the plus sign in the denominator. Thus $(v + v_D) = (v + v_S)$ and $f' = f = 500.0\,\mathrm{Hz}$.

(c) Relative to the air the locomotive is moving at $v_S = 20.00\,\mathrm{m/s}$ away from the uncle. Use the plus sign in the denominator. Relative to the air the uncle is moving at $v_D = 10.00\,\mathrm{m/s}$ toward the locomotive. Use the plus sign in the numerator. Thus

$$f' = f\,\frac{v + v_D}{v + v_S} = (500.0\,\mathrm{Hz})\left(\frac{343\,\mathrm{m/s} + 10.00\,\mathrm{m/s}}{343\,\mathrm{m/s} + 20.00\,\mathrm{m/s}}\right) = 486.2\,\mathrm{Hz}\ .$$

(d) Relative to the air the locomotive is moving at $v_S = 20.00\,\mathrm{m/s}$ away from the girl and the girl is moving at $v_D = 20.00\,\mathrm{m/s}$ toward the locomotive. Use the plus signs in both the numerator and the denominator. Thus $(v + v_D) = (v + v_S)$ and $f' = f = 500.0\,\mathrm{Hz}$.